

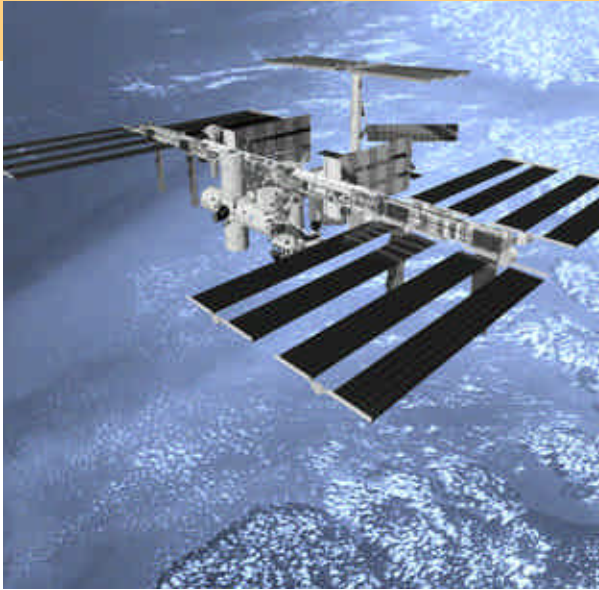
Recycling in Space



Why We Need Regenerative
Life Support Systems

Recycling in Space -

Why We Need Regenerative Life Support Systems



National Aeronautics and Space Administration

Lyndon B. Johnson Space Center

Space & Life Sciences Directorate

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Overview

The human body is two-thirds water. It is therefore necessary for humans to consume a sufficient amount of water, as well as oxygen and food, on a daily basis in order to sustain life. Scientists have determined how much water, air, and food are used per day per person for life on Earth. Space scientists have learned how much water, air, and food are actually necessary per day per person for life in space.



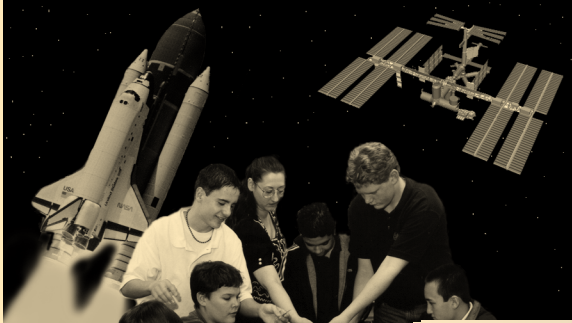
A problem arises with long-duration missions on the Space Shuttle, on the space station, and, in the future, on missions to the Moon and Mars. The problem is that it is physically impossible for astronauts to take with them all the air, water, and food they will need for a long-duration mission. Recycling in space therefore becomes extremely important.

The necessity to recycle water for consumption, as well as for cleanliness, becomes most apparent as the time spent in space increases. The amounts of water required have been estimated at 2.42 kg/day (5.32 lb) per person for drinking water and food hydration, 6.77 kg/day (19.89 lb) per person for personal hygiene, and up to 17.95 kg/day (39.49 lb) per person for laundry and housekeeping. Given these figures, a 90-day mission with six astronauts would require 31,400 kg (9,400 gallons or 69,224 lb) of water. The costs associated with launching and storing such large amounts of water are prohibitive and will force water reclamation, in varying degrees, on future missions.

On Mercury, Gemini, and Apollo flights, water supplies were either carried aboard or produced as a by product of the fuel cells that produced electrical power. This water was of a quantity and quality sufficient and suitable for human consumption. Water for personal hygiene needs was minimal on these short- duration flights. The water produced by the fuel cells on the Space Shuttle is more than enough to replenish the supply carried aboard and used for food rehydration, drinking, and tooth brushing. Future longduration missions, such as those on the International Space Station (ISS), will incorporate the ability to reclaim and recycle water from condensation, wash water, and urine.



Background for Teachers



This activity gives students experience with the concept of Recycling fluids and gases.

Prerequisites

Students should be able to:

- Multiply and divide decimals to two places
- Use simple reasoning and deduction
- Record data on a data sheet
- Use the metric system.



Objectives/Standards

This activity fulfills the **National Science Education Standards** by developing students' abilities to:

- Use mathematics in all aspects of scientific inquiry
- Think critically and logically to make the relationships between evidence and explanations
- Communicate scientific procedures and explanations.



Key Questions

Ask the following questions:

- What does it take to sustain life?
- What are some of the different ways that we use water every day?
- How can astronauts have enough water and air for long-duration missions?
- Why is purifying and recycling water and air necessary?

Pre-Activity Discussion



What does it take to keep us alive?

Start the activity by asking the students to pretend that the classroom is a spaceship

destined for the Moon or Mars. Tell them the sinks don't bring in water and the drains don't go any where, the air conditioning vents don't provide fresh, cool (or warm) air, and the door can't be opened to leave the room. Ask What would be required to keep you alive for 3 months or longer? Ask What do you do every day to keep yourself alive? *The answers are: food, water, air, a comfortable temperature to provide for their bodies and ways to remove wastes, including the heat their bodies generate.* Here are activities to produce those answers.

Food is usually the first answer, followed closely by water or drink. At this point, ask **How much food do you eat every day?** Make a reasonable guess on the basis of how big a lunch is or weigh a few students' lunches.

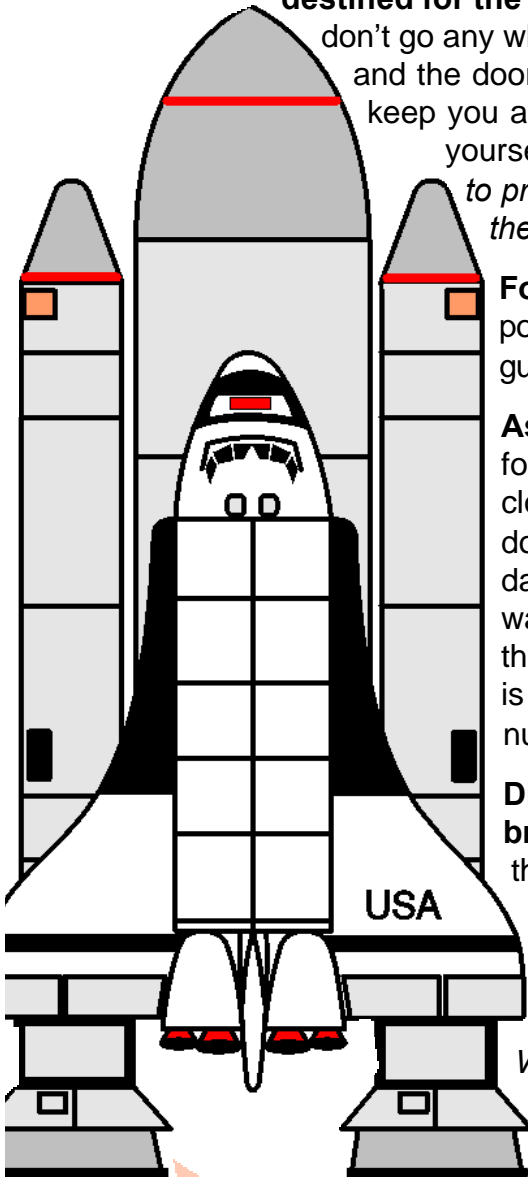
Ask them to name all the ways water is used each day: preparing food, brushing teeth, bathing, washing hands, drinking, washing clothes, and washing dishes. Where does all that water go once it is down the drain? Ask them to estimate how much water they use every day. For a bath, suggest they think about how many 1-gallon jugs of water would fit 1-layer deep in their bath tub. Most can visualize this and the answer is about 3 rows side by side, 9 or 10 jugs long. Since each is a gallon, the answer is 27 to 30 gallons, which is close to the correct number. Do the same with the other water needs.

Discuss the need for air, specifically oxygen. Have them hold their breath as long as they can. When they can't hold it anymore, ask them what their body needed and was deprived of while holding their breath. Ask "What do you inhale every time you breathe?" *The answer is oxygen.* Ask "What do you exhale?" *The answer is carbon dioxide and water vapor.* Most know carbon dioxide but not water vapor. Ask "Can you see your breath outside on a cold morning?" *What they are actually seeing is moisture condensing as they exhale.* Ask "How does oxygen get to you and where does the carbon dioxide go?" *On Earth, the plants constantly recycle it for us. Also, there is a huge amount of oxygen in the Earth's atmosphere.* But, if you had

only the air in your spaceship (classroom), you would quickly run out of oxygen to breathe, and carbon dioxide would build up.

Demonstrate removing heat, by doing 25 jumping jacks. Ask how do you feel after exercising and how hot are you? Heat has to be removed for you to survive. Even when you aren't exercising, your bodies produce heat. If the air conditioner wasn't bringing cool air into the room, you would eventually get too hot.

The fundamental point of this activity is that you cannot take enough air water, and food with you for long trips to outer space and that you have to recycle air and water initially, and food later, to be able to do space exploration. Sizes of materials in this activity were selected to make the water overflow the space station. One bead was selected to equal 4.5 kg of water to get 720 or so beads in the space station case. When using this exercise with these numbers, use items of equivalent size to those suggested. Alternate material examples are discussed under, **The Kit**. Ask "Can you can take with you all the water and oxygen you will need?" Discuss how to recycle the stale air and dirty water into fresh air and clean water for the crew of the spaceship.



Earth Versus Space Requirements

The items that the astronauts need are in the left-hand column of the table entitled ***How much stuff does it take to keep you alive?*** The average amounts used on Earth are in the second column, and the amounts allowed for space are in the third column. References are footnoted on that table to indicate where these amounts can be found. The space allotments are so much smaller because water is very heavy and we can't carry that much water with us. The amounts on earth are typical amounts a US citizen uses based on numbers from a college textbook on water and waste water treatment. One reason the amounts used on Earth are considerably larger is that people spend a lot of time running the faucet waiting for the water to get hotter or colder. In addition, washing machines and dishwashers are not as efficient as they could be, because water is not in scarce supply on Earth. In space, depending on how long we are going to be gone, the crew gets different luxuries. For a short Space Shuttle mission, the crew gets water for drinking, food preparation, and tooth brushing. (They use wet wipes to clean their hands, and Space Shuttle toilets are flushed with air.) But for a 90-day space station mission, they are going to want a shower, and maybe to do some laundry. For a mission with a longer stay on the Moon, they may also wash dishes.

Use data requirements A, B, and C to show students how many consumables are required to sustain life for different sizes of crews and different lengths of missions. You need consumables for each person for each day he or she is gone, so the point of the exercise is to calculate how much is required for the whole crew for the entire mission. Each of the three missions is different. In each case, sum the amount of water from all the different categories of water usage. The food and oxygen are only single items.



The Kit

Each life support need is represented by a different object in the kit. Water is represented by hard plastic beads, because like the beads, it is not compressible. Oxygen is represented by pom-poms, because it is compressible just like the gas. Food is represented by raisins, because they are dried like space food. The astronauts are represented by little figures of some type

that fit in the spaceship. You can use a toilet paper tube for the Space Shuttle and a paper towel tube (which may be cut down to size) for the Space Station. Wrap them in construction paper and cover one end so things can be dumped into them. (Use your imagination and be creative.) Other examples of materials to use without changing the amounts are dried green peas or small dried beans (like the little red ones) for beads, cotton balls for pom-poms, face sponges for the crew, a small Easter egg, a bubble gum machine toy bubble for the small box scrubber, a TIC-TAC container for the medium scrubber, and a film canister for the large scrubber.

Calculations

After students multiply the needs for one person for one day by the number of people and number of days, they will sum the different water uses for each different mission. Tell them that each raisin is so many (look at the key for the right number) pounds/kg of food, and have them divide the amount of food needed by how much each raisin represents to figure out how many raisins they need for their mission. Do the same with the water and oxygen. Then remind them that we have to remove the carbon dioxide and heat so they better add a small box (scrubber) of some kind to purify and cool the air. Have them put everything, including the astronauts into the ship and see what happens. For the Space Shuttle, everything should fit. For the Space Station, the water shouldn't all fit. To take all the water needed, the astronauts would have to be working in a swimming pool. Then, we talk about recycling water and the processes for doing that. Methods of recycling water include filtering it, and heating it. For the Space Station, little boxes are used to purify the air and water, and then there is room for the astronauts. For a mission to Mars or to the Moon with an extended stay there, the food supply would be limited. In this case, the astronauts would have to grow food from plants to provide enough to eat. Research on the technology needed to grow healthful, edible plants in space ongoing.

How much stuff does it take to keep you alive?

Item	On Earth kg per person per day ¹	In Space kg per person per day ²
Oxygen	0.84	0.84
Drinking Water	10.00	1.62
Dried Food	1.77	1.77
Water to Rehydrate Food	4.00	0.80
Water to Brush Teeth	5.00	0.81
Water to Flush Toilet	88.00	0.50
Water to Shower	50.00	3.64
Water to Wash Hands	20.00	1.82
Water to Wash Clothes	16.00	12.5
Water to Wash Dishes	12.00	5.45

A- Requirements for the Shuttle

Item	In Space kg per person per day
Oxygen	0.84
Drinking Water	1.62
Dried Food	1.77
Water to Rehydrate Food	0.80
Water to Brush Teeth	0.81



B- Requirements for the International Space Station

Item	In Space kg per person per day ²
Oxygen	0.84
Drinking Water	1.62
Dried Food	1.77
Water to Rehydrate Food	0.80
Water to Brush Teeth	0.81
Water to Flush Toilet	0.50
Water to Shower	3.64
Water to Wash Hands	1.82



C- Requirements for a Mars Mission

Item	In Space kg per person per day ²
Oxygen	0.84
Drinking Water	1.62
Dried Food	1.77
Water to Rehydrate Food	0.80
Water to Brush Teeth	0.81
Water to Flush Toilet	0.50
Water to Shower	3.64
Water to Wash Hands	1.82
Water to Wash Clothes	12.5
Water to Wash Dishes	5.45

¹From Water Quality by Tchobanoglous and Schroeder, 1987 Addison-Wesley Pub.; Reading Mass., USA

²From Space Station Architectural Control Document

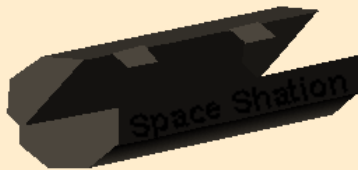
Materials

The recycling activity requires the following materials:

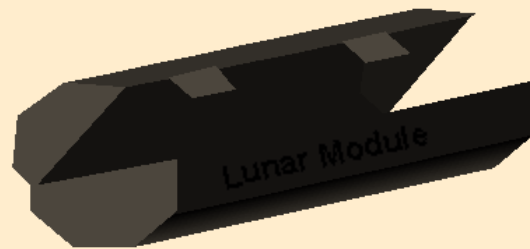
- 1 transparency of data sheets with A,B,and C
- 1 transparency of Life Support Consumable worksheet
- 1 Life Support Consumables worksheet for each student
- Student calculators (at least one per group)
- 6 mini-sized figures/objects to represent astronauts
- 16 compressible pom-poms (approximately 1 inch in diameter) to represent oxygen (cotton balls may be substituted)
- 1 bag of 720 medium-size (1/4") beads to represent water
- 1 large bag/box/canister of raisins to represent dehydrated food
- 3 containers with lids (graduated in length), to represent the Space Shuttle, Space Station, and a lunar or Mars base module (toilet paper and paper towel tubes may be used)



(approx. 2" x 4"

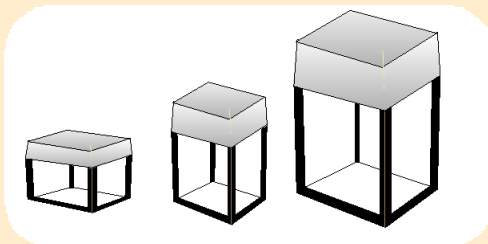


approx. 2" x 6"



approx. 2" x 8")

- 3 small graduated boxes with lids to represent the air scrubbers (small box for air on the Space Shuttle, medium and large boxes for air and water on the Space Station and for a Moon or Mars mission, Film canisters, gumball machine toy "bubbles," small jewelry boxes, etc. may be substituted).



(approx. 1" x 1" x 0.75"

approx. 1" x 2" x 0.75"

approx. 1.25" x 1.25" x 2.25")

Procedures

Time Frame

Preparation: 30–45 minutes

Activity: The classwork and discussions may be extended over three or four class periods.

Getting Ready

To prepare for activity do the following:

1. Read "Pre-Activity Discussion."
2. Read "Background for Teachers" section.
3. Make transparency of data sheets A, B, and C.
4. Make transparency of "Life Support Consumables Worksheet."
5. Copy "Life Support Consumables Worksheet" for each student.

Recycling in Space Activity

Instruct your students in the following steps of the experiment procedure:

1. **Divide the class.** Divide the class into five groups of mission design engineers—one for food, one for air, and three for water - one water group each for Shuttle, Station, and Mars. (Teacher note: How/if the class is divided has no effect on the validity of the exercise.) Go through the **Pre-Activity Discussion** sections 1 and 2 on “**What does it take to keep us alive?**” and “**Earth versus Space Requirements**” with the class.

2. **Distribute a copy of the “Life Support Consumables Worksheet.”** Ask the students how they are going to figure the total amount of food (or water or oxygen) needed for all the astronauts for the number of days in the mission if they know how much food (or water or oxygen) one astronaut needs each day. Ask them what math operation they have to do to figure out the total. *The answer is multiplication.*

Total needed = amount needed per person per day x number of people x number of days

Have the air and food groups calculate the amount of their item required for all three missions—Space Shuttle, Space Station, and Mars. Have each water group calculate the amount of water needed for each different use (hand wash, showers, etc.) for their mission scenario and then sum all the water needed for their mission.

Describe the contents of the kit to the class and what each item represents and why as in the **Pre-Activity Discussion in The Kit.**

3. **How much do you need?** Then, for each mission, have the five groups of mission design engineers figure the number of beads (water), raisins (food), or pom-poms (oxygen) needed. The amount of water, food, and oxygen represented by each bead, raisin, and pom-pom, respectively, is given on the *teacher’s keys*. After telling the class these amounts, ask them what math operation they have to do to figure out the number needed. *The answer in this case is division.*

Number needed for the mission =
$$\frac{\text{Total amount of water, food, or oxygen needed}}{\text{Amount represented by each bead, raisin, or pom-pom}}$$

The air and food designers will have to calculate their numbers for each mission and the water groups will have only one number for their specific mission.

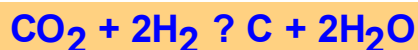
4. **Conduct the experiment.** When the five groups have their totals and discussion has ceased, a spokesperson from each group will instruct a “mission integration engineer” as to how many beads, raisins, and pom-poms to put into each “vehicle” (container), along with the correct number of “astronauts.” Then remind them that we have to remove the carbon dioxide and heat so they better add a small box (scrubber) of some kind to purify and cool the air. Have them put everything, including the astronauts into the ship and see what happens. For the Space Shuttle, everything should fit. As the amounts increase, the need for recycling will become obvious. The space station will be totally full of water and there will be no room for the astronauts. The Mars module will be filled with food. Ask the students for possible solutions to their dilemma.



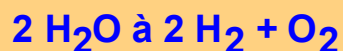
Wrap-up Session

1. Analyze and discuss the data collected.
2. Discuss the requirements for air and water in space, and why there is a need for recycling.
3. Ask “How can you recycle the air and clean the dirty water so that you could stay alive indefinitely?”

Have them look at the carbon dioxide molecule (CO_2) to see what it has in common with the oxygen molecule (O_2). There are a number of technologies that recover this O_2 molecule for the astronauts to breathe again. One of them converts CO_2 into C using H_2 —hydrogen—and forming water (H_2O) as a product. The reaction looks like this:



The water is then split using electricity to form H_2 —hydrogen—and O_2 —oxygen, like this:

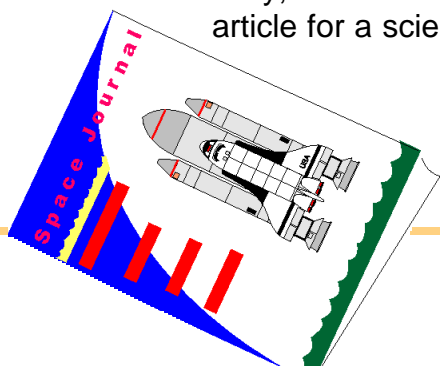


The oxygen is used by the crew, and the hydrogen is reused in the reaction with CO_2 .

There are a number of ways to clean the soap from wash water and even the wastes from urine. The water can be filtered through chemical beds to adsorb the contaminants (soap, urea, etc.), just as it is in the pitchers with the replaceable cartridges that lots of people use to purify water at home. Or, you can put it through a phase change (evaporate or freeze it). It can be evaporated (boiled) and recondensed. The contaminants stay in the pan and the clean water comes across in the vapor and condenses out purified. Try boiling water with a lot of salt in it until the water is gone. What is left in the pan once all the water has boiled away? If you could capture the water that boiled into the air and recondense it, you would find it is much purer than what you started with in the pan. You can also purify water by freezing it. One thing to try is to make colored ice cubes with different food coloring. Freeze the colored water and then examine the ice cubes. See which ones show gradients in the color. The color concentrates in one part of the cube because this part freezes last. This works better for some colors than others (green worked best and yellow the worst when I tried it). The water in the clearer part of the ice cube is purer than the water in the darker part.

For a mission to Mars or to the Moon with an extended stay there, the food supply would be limited. In this case, the astronauts would have to grow food from plants to provide enough to eat. Research on the technology needed to grow healthful, edible plants in space is ongoing.

4. Finally, have students write their findings in a lab notebook and, optionally, compose an article for a scientific journal.



Formula Key

Formulas

Energy required = power x time (in hours)

$$162000.0 = 75 \times 90 \times 24 \text{ (station)}$$

Stored Fuel-Tank sets = Energy required ÷ Energy per Tank set

$$192.9 = 162000.0 \div 840 \text{ (station)}$$

Solar Array Area = power x solar array area per kW

$$3262.5 = 75 \times 43.5 \text{ (station)}$$

Radiator Area = waste heat out x radiator area per kW

$$375 = 75 \times 5 \text{ (station)}$$

of Solar arrays = solar array area ÷ area per solar array

$$5 = 3262.5 \div 652.5 \text{ (station)}$$

of Radiator panels = radiator area required ÷ area per radiator

$$12 = 375 \div 31.25 \text{ (station)}$$

Power in = waste Heat out

One Solar Array = 652.5 m²

One radiator panel = 31.25 m²

Energy per tank set = 840 KW hrs



Shuttle - Radiators go in Payload Bay door

ISS - Radiators and Solar Arrays go on the Truss (dowel/rod)

Moon - Radiators go in parabolic shade; Solar Arrays sit on Moon's surface



name _____

Formulas

Energy Requirements Worksheet

Energy required = power x time (in hours) 75kW x 90 days x 24 hrs

Stored Fuel-Tank sets = Energy required ÷ Energy per Tank Set

Solar Array Area = power x solar array area per kW

Radiator Area = waste heat out x radiator area per kW

of Solar arrays = solar array area ÷ area per solar array

of Radiator panels = radiator area ÷ area per radiator



Power in = Waste Heat out
One Solar Array = 652.5 m²
One radiator panel = 31.25 m²
Energy per tank set = 840 Kw Hrs

Shuttle - Radiators go in Payload Bay door

ISS - Radiators and Solar Arrays go on dowell rod

Moon - Radiators go in parabolic shade;

Solar Arrays go on Moon's surface

Life Support Consumables Worksheet Key

Item	Amount kg/person/day	Shuttle 6 people for 8 days kg	Station 4 people for 90 days kg	Mars Mission 6 people for 900 days kg
Oxygen	0.84	40.32	302.40	4536.00
Drinking Water	1.62	77.76	583.20	8748.00
Dried Food	1.77	84.96	637.20	9558.00
Water to Rehydrate Food	0.80	38.40	288.00	4320.00
Water to Brush Teeth	0.81	38.88	291.60	4374.00
Water to Flush Toilet	0.50		180.00	2700.00
Water to Shower	3.64		1310.40	19656.00
Water to Wash Hands	1.82		655.20	9828.00
Water to Wash Clothes	12.50			67500.00
Water to Wash Dishes	5.45			29430.00
Total Water	27.14	155.04	3308.40	146556.00
Total Food	1.77	84.96	637.20	9558.00
Total Oxygen	0.84	40.32	302.40	4536.00
# of beads		34.5	735.2	32568.0
# of raisins		2.8	21.2	318.6
# of pom-poms		2.0	15.1	226.8
Or with regenerative ARS/WRS				
# of beads		34.5	18.1	18.1
# of raisins		2.8	21.2	7.1
# of big pom-poms		2.0	0.1	0.1

Each bead/raisin/pom-pom equals the following:

4.5 kg water/bead
30.0 kg food/raisins
20.0 kg O2/big pom-pom



Energy Requirements Worksheet Key

Thermal Requirements

	Units	Shuttle 15 kw 8 days	Station 75 kW 90 days	Moon 75kW 180 days
Stored Chemical Fuel	kW hours/ tank set	840.0	840.0	840.0
Solar Array Area	m2/kW		43.5	87
Radiator Area	m2/kW	5	5	10
Radiator Area with Shade	m2/kW			3
kWhrs Required		2880.0	162000.0	324000.0
Stored Fuel-Tank Sets Required		3.4	192.9	385.7
Solar Array Area Required	m2		3262.5	652.5 *
Radiator Area Required	m2	75	375	750**
Radiator Area Required with shade	m2			225
# of Solar Arrays			5	10
# of Radiator Panels		2.4	2	24
# of Radiator Panels with shade				7.2



*652.5 m2/solar array

** 31.25 m2/radiator panel

Energy Requirements Worksheet

name _____

Item	Units power = time =	Shuttle 15 kw 8 days	Station 75 kW 90 days	Moon 75kW 180 days
Energy per Tank Set for Stored Fuel	kW hours/tank set	840.0	840.0	840.0
Solar Array Area per kW	m2/kW		43.5	87
Radiator Area per kW	m2/kW	5	5	10
Radiator Area per kW with Shade	m2/kW			3
Energy Required in kW hours	see formula			
How Many Stored Fuel -Tank Sets are Required?				
How Much Solar Array Area Required?	m2			
How Much Radiator Area Required?	m2			
How Much Radiator Area Required with Shade?	m2			
# of Solar Arrays				
# of Radiator Panels				
# of Radiator Panels with shade				





name _____

Life Support Consumables Worksheet

Item	Amount kg/person/day	Shuttle 6 people for 8 days (kg)	Station 4 people for 90 days (kg)	Mars Mission 6 people for 900 days (kg)
Oxygen	0.84			
Drinking Water	1.62			
Dried Food	1.77			
Water to Rehydrate Food	0.8			
Water to Brush Teeth	0.81			
Water to Flush Toilet	0.50			
Water to Shower	3.64			
Water to Wash Hands	1.82			
Water to Wash Clothes	12.50			
Water to Wash Dishes	5.45			
Total Water	27.14			
Total Food	1.77			
Total Oxygen	0.84			
# of beads				
# of raisins				
# of pom-poms				

